NASA TECHNICAL TRANSLATION

NASA TT F-16977

THE NEW TRANSONIC AND SUPERSONIC WIND TUNNEL OF THE AERODYNAMIC INSTITUTE

G. Freytag

(NASA-TT-F-16977) THE NEW TRANSONIC AND SUPERSONIC WIND TUNNEL OF THE AERODYNAMIC INSTITUTE (Agnew Tech-Tran, Inc., Woodland Hills, Calif.) 18 p HC $3.50 CSCL 14B

N76-21222

Unclas

G3/09 21448

Translation of "Der neue Transonic- und Uberschallwindkanal des Aerodynamischen Instituts", Rheinisch-Westfalische Technische Hochschule, Aachen, West Germany, Aerodynamics Institut, Abhandlungen, No. 22, pp 233-238, 1975

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546 APRIL 1976

STANDARD TITLE PAGE

1. Report No. NASA TT F-16977	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle THE NEW TRANSONIC AND SUPERSONIC WIND TUNNEL OF THE AERODYNAMIC INSTITUTE		5. Report Date April 1976
		6. Performing Organization Code
7. Author(s) G. Freytag		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address Agnew Tech-Tran Inc. Woodland Hills, Calif. 91364		11. Contract or Grant No. NASw-2789
		13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration, Washington, D. C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes
Translation of "Der neue Transonic- und Überschallwindkanal des Aerodynamischen Instituts", Rneinisch-Westfalische Technische Hochschule, Aachen, West Germany, Aerodynamics Institut, Abhandlungen, No. 22, pp 233-238, 1975.

16. Abstract The available compressor installations restrict the use of the new wind tunnel to an intermittent operation schedule. Operational details are discussed, taking into account the employment of suction and pressure. The design of the wind tunnel is considered, giving attention to the Laval nozzle, the free jet chamber, the diffusor, and the transonic chamber. The wind tunnel was installed in the Aerodynamic Institute at the end of 1974.

17. Key Words (Selected by Author(s))	18. Distribution Statement Unclassified-Unlimited		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 16	22. Price

NASA HQ

THE NEW TRANSONIC AND SUPERSONIC WIND TUNNEL
OF THE AERODYNAMIC INSTITUTE

G. Freytag*

1. Introduction

/233**

The German Research Association (Deutsche Forschungsgemeinschaft) authorized a wind tunnel for the fundamental research work of the Aerodynamic Institute within the scope of the special research area 83. This tunnel can be operated at subsonic and supersonic as well as at transonic velocities. The dimensions of the testing cross section are 40 x 40 cm^2 and the maximal attainable airflow times are around 8 seconds. Although several new tunnel types [1] are being tested at the present, especially for transonic velocities with the objective of achieving high Reynolds numbers, the new tunnel of the Aerodynamic Institute operates with steady state atmospheric conditions and has a conventional design. The suction operation applied in it contains some details of technical interest which will be described below.

The tunnel project work was carried out under the supervision of prof. Naumann. His extensive experience in the design and planning of wind tunnels constituted a welcome help for the author during the preparation of this paper. In the construction, knowledge and experience of the appropriate literature [2]-[15] were utilized; these are listed at the end of the paper.

2. Project Work of the Tunnel

---

* Certified Engineer, scientific assistant of the Aerodynamic Institute of the Rheinisch-Westfälische Technische Hochschule (Rhineland-Westphalia Technical University) Aachen.

** Numbers in the margin indicate pagination in the foreign text.

Because of the existing tank and compressor installations, the tunnel can be operated only intermittently in the total velocity range. Four tanks with a total capacity of 380 m^3 for pressures up to 13 bar are available to the Institute, as well as two Balcke rotary compressors with an output of a total of about 3200 Nm^3/h in suction operation up to about 99% vacuum, or about 3600 m^3/h in pressure operation to about 9 bar, and a Demag screw-type compressor with an output of about 4700 m^3/h in suction operation (referred to 0,1 bar and 20°C suction intake condition) up to about 94% vacuum or about 5100 m^3/h in pressure operation up to about 11 bar.

For these data a research project for suction operation and a second one for pressure operation have been prepared to consider the requirements for a test chamber with the largest cross section possible and witn sufficient air-flow times. These are outlined briefly in the following.

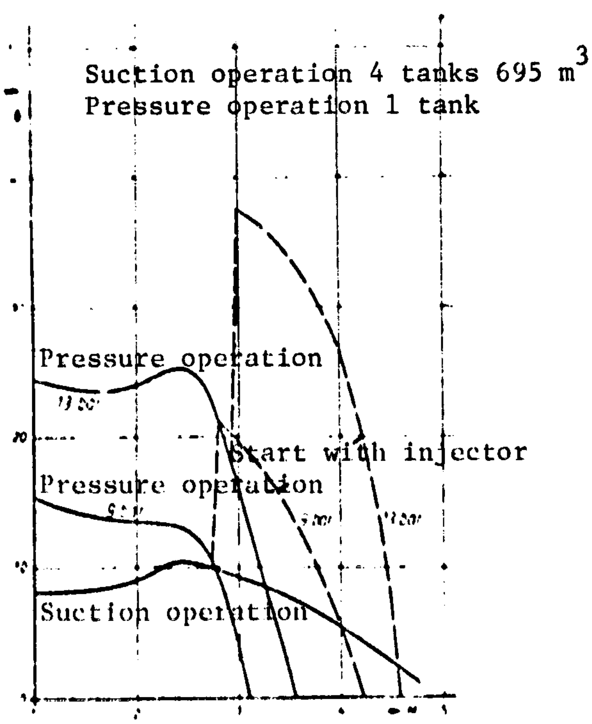

Fig. 1. Air-flow times of a 40 x 40 cm^2 wind tunnel without losses.

3. Suction Operation

During the intermittent suction operation the test air is sucked from the atmosphere through the working section into an evacuated tank. Thus the possible air-flow times are determined by the size of the available tank capacities. Computations of the air-flow times--their results are represented in Fig. 1 --showed that with the existing tank installations for a testing cross section of 40 x 40 cm^2 about 8 seconds can be can be achieved up to a Mach number (critical velocity ratio) of $M = 3,5$. These computations do not take into account the flow structure and losses in the tank installations. Because this cross section and the mentioned air-flow time are sufficient for the tasks to be performed in the Insitute, further project work was performed with these data.

A tank with a capacity of about 380 m^3 at the tunnel end was assumed for the computation of the air-flow times in figure 1. The tank installation of the Aerodynamic Institute, however, consists of 4 tanks with a capacity of about 95 m^3 each; 3 of these are connected through connection lines with the suction tank. Due to the low initial pressures in the tanks, the flow in the connection lines may block at cross sections which are too small, so that the penetrated air weight does not rise despite the increasing pressure in the suction tank. Therefore the flow in the wind tunnel cannot be maintained for as long as with a tank of the same size. The correction of the thus caused loss of airflow time was performed with the 15 x 15 cm^2 wind tunnel of the Aerodynamic Institute and to assure the extrapolation on the 40 x 40 cm^2 tunnel additionally with a pilot tunnel with a cross section of 30 x 30 cm^2. In these tests the chronological pressure course in the suction tank was measured when none, one, two or three more tanks were con- /234
nected. Based on the test results, figure 2 reproduces the chronological pressure courses for the pilot tunnel: the diameter of the connection lines was 500 mm. If only the suction tank is connected, the pressure rise is almost linear. It is evident from the ascending curve that the tank filling lies between isothermal and adiabatic state change. If no blocking would occur in the connection lines, the course of the filling curves for 2, 3 and 4 connected tanks also should be almost linear, and the curves should differ in the slope only. Figure 2, however, shows that effective overflow occurs only above

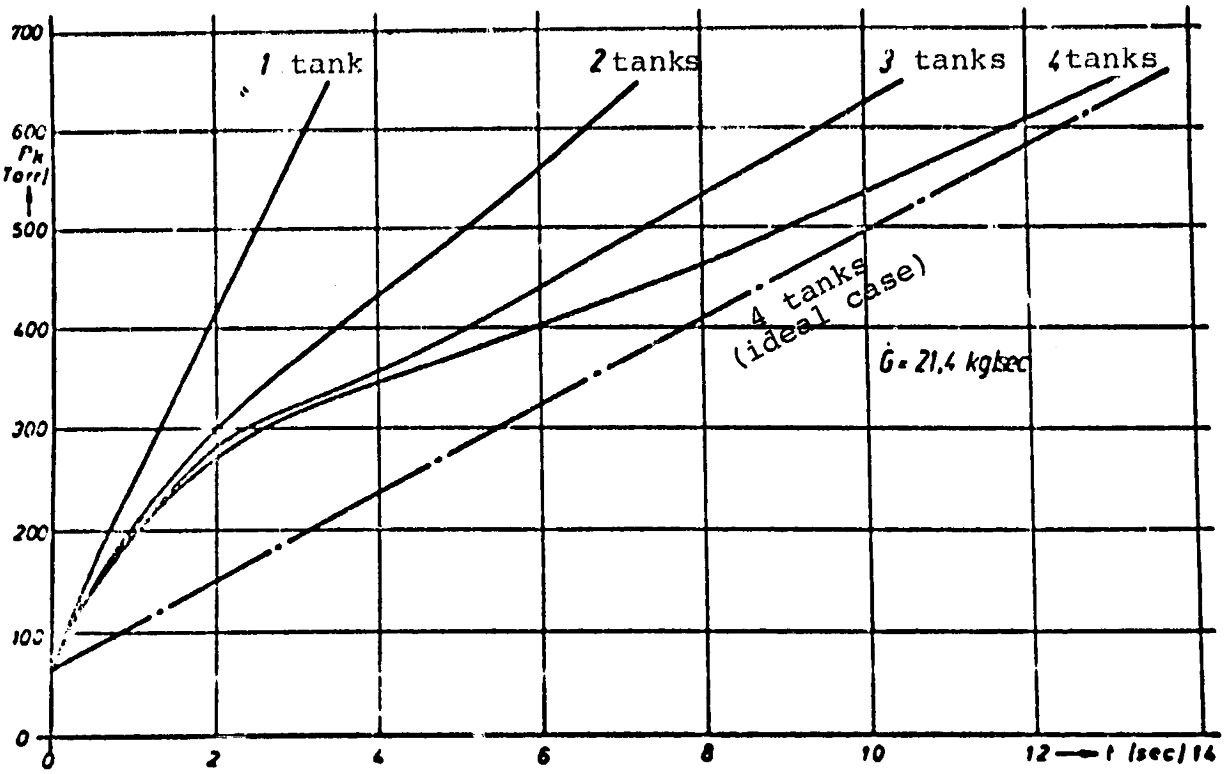

Fig. 2. Pressure courses in the suction tank throughout the air-flow time for 30 x 30 cm^2 Pilot tank channel (connection lines NW 500).

about 300 - 350 torr. This filling behavior of the tank installation has unfavorable effects, in particular with higher Mach numbers, as the tank pressure at which the flow in the tunnel collapses decreases more and more with rising Mach number. Though the rate of airflow decreases with the Mach number (Fig. 3) and thus makes possible a longer air-flow time, the connection lines between the tanks had to be enlarged in order to allow for air-flow times of sufficient duration.

The relatively low Reynolds numbers which occur during the suction operation, due to the low density in the working section, are of disadvantage. In figure 5 the attainable Reynolds numbers are plotted over the Mach number. The tunnel height l = 40 cm and l = 20 cm were each used once as reference length because the model dimensions --in particular in the transonic velocity range--must be substantially

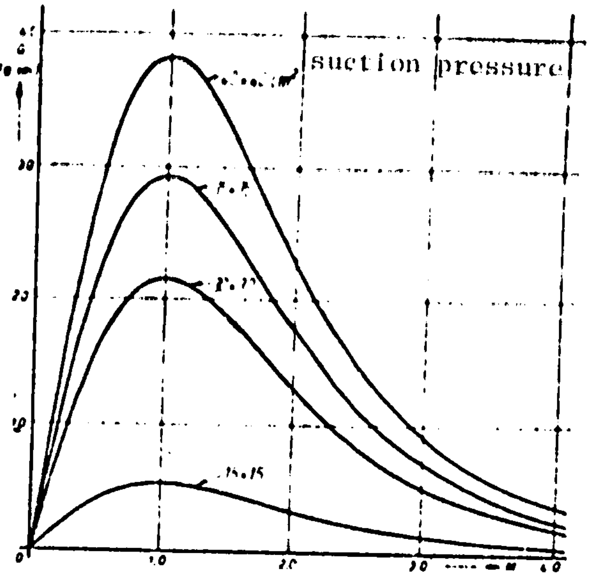

Fig. 3. Rate of air-flow for different dimensions of the test chamber.

smaller than the tunnel height. For Mach numbers > 1.4, half the measuring rhombus length is selected as reference length.

Because the air must be dried before entering the tunnel in order to avoid condensation, a drying filter element was designed which operates with silica gel as adsorption agent. The required gel quantity amounts to about 9000 kg.

The application of cryogenic drying was excluded due to excessive cost.

4. Pressure Operation

In the second research project the tunnel was laid out as a pressure tunnel. Contrary to the suction tunnel where steady state pressure and steady state temperature remain almost constant during the entire test time, in the pressure tunnel both values must be regulated before the air enters the tunnel. The steady /235
state pressure is regulated with a valve. The steady state temperature may be regulated once by maintaining the test air during the measuring time at ambient temperature. This requires only minor effort because only the decrease of temperature in the pressure reservoir caused by the pressure drop must be compensated. At the given tunnel and tank dimensions, about 500kg of heat accumulator material (for instance aluminum) with a volume of about 0,2 m^3 would be required, which can be stored in a tank used as a quiescent tank. Another possibility to regulate the steady state temperature

requires more effort; it allows, however, for a certain variation of the Reynolds number. The test air is heated; thus the condensation at high Mach numbers is impeded. This type of temperature control is used in all hypersonic tunnels; it may be provided for a later improvement of the test installations.

The Balcke rotary compressors at the Institute produce--as mentioned above--maximal pressures of 9 bar. However, at high Mach numbers or large Reynolds numbers higher pressures may be required. In that case, a tank set is loaded with a volume of 24 m^3 through two high-pressure compressors of the Institute (to 350 bar), and the tanks surged to 9 bar are brought to their allowable extreme pressure of 13 bar by this set.

Figure 1 shows that substantially longer air-flow times can be reached in pressure operation than in suction operation. At a pressure of 9 bar the air-flow times for one pressure reservoir tank alone are about 15.5 sec at $M = 1$ and about 12.9 sec at $M = 2.5$. At 13 bar the respective air-flow times amount to 24.5 sec or 25 3 sec.; however, they drop down to zero at relatively low Mach numbers ($M = 3.2$ or 3.6). This disadvantage can be avoided with the aid of an injector at the start of the tunnel. The air-flow times attainable with this device cannot be computed due to the unknown efficiency factors of the injector. The estimated course is plotted in a broker line in figure 1. It was assumed that the start injector is connected as of $M = 2.8$ at a pressure of 9 bar and as of $M = 3$ at 13 bar. This way it would be also possible to attain Mach numbers of about 4.5. At a reference length of $l = 40$ cm the maximal Reynolds number amounts to about $14 \cdot 10^6$.

The above mentioned advantage of the pressure operation is opposed, however, by decisive disadvantages. Because the Balcke compressors do not produce compressed air which is free of oil, the oil mist would always stain the observation window; this would also substantially complicate the optical measurement of air-flow fields. There is another disadvantage in the form of pressure disturbances which--caused by the control valve--may falsify measurement of unstable air-flow actions (for instance surge fluctuations). Since in addition to these disadvantages a 20% higher production expense resulted, it was decided to use suction operation.

5. Wind tunnel design

The upper part of Figure 4 shows the tunnel for subsonic and supersonic operation. For transonic operation a transonic chamber (d) with perforated walls is inserted behind the Laval nozzle (c) /236 (figure 4, lower section). A provided air dryer is flanged before

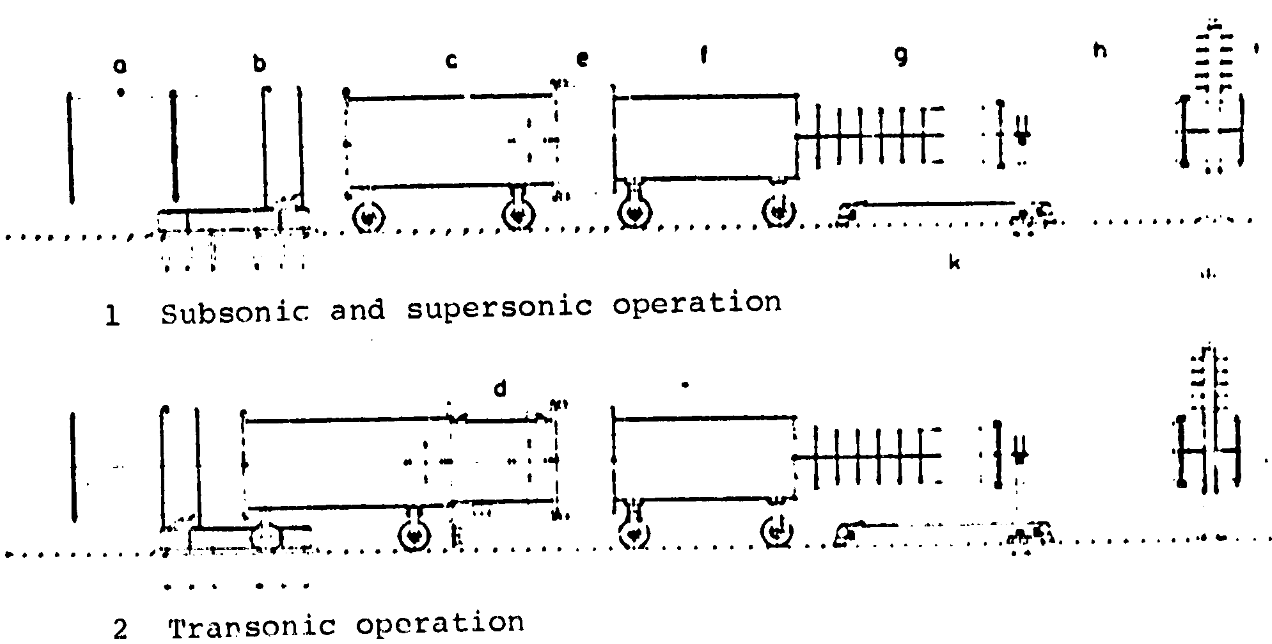

Fig. 4. Wind tunnel arrangement (layout)

a: Antechamber adapter
b: Antechamber
c: Laval nozzle
d: Transonic chamber
e: Free jet chamber
f: Bilamellar diffusor
g: Fixed diffusor
h: Telescopic tube
i: Quick-action stop valve
k: Sliding cylinder

the antechamber adapter (a); behind the quick-action stop valve (i) the vacuum tanks. The total length between these two points is 16.3 m. The model is attached to a model support in the free jet chamber (e). A high-speed closure is installed at the forward end of the chamber; after opening this closure the rear section of the tunnel is moved about 2.5 m backwards by the sliding cylinders attached at the bottom (k) on rails. In doing so, the fixed diffusor (g) is slid into the telescopic tube (h). When closed, the gap between fixed diffusor (g) and telescopic tube (h) is sealed off by an inflatable labyrinth box. The installation of the transonic chamber (d) is scheduled in such a way that the optics must not be moved. The Laval nozzle (c) is movable too and the antechamber (a and b) is divided into two parts. The antechamber adapter (a) is of the same length as the transonic chamber and is removed during conversion to transonic operation; this way the observation windows for the complete velocity range always remain in the same spot. Thus, a readjustment of the optical systems is avoided. In order to prevent vibrations of the tanks, caused by the inflow of the test and opening of the quick-action stop valve, from being passed into the tunnel, the point of reference of the tunnel was placed at the antechamber. A connection to these parts exists only through the inflated seal at the telescopic tube.

5.1 Laval nozzle

The Laval nozzle (c), manufactured by the Hausammann and Isler company (Zurich), is designed as a continuously adjustable nozzle. The adjustment covers a Mach number range from $M = 1$ to about 5 and is carried out through a hydraulic cylinder which can be activated by a servo system installed at the sidewall of the nozzle.

The nozzle contour is produced with one fixed swivel nozzle block (top and bottom) and flexible sheet metal panels

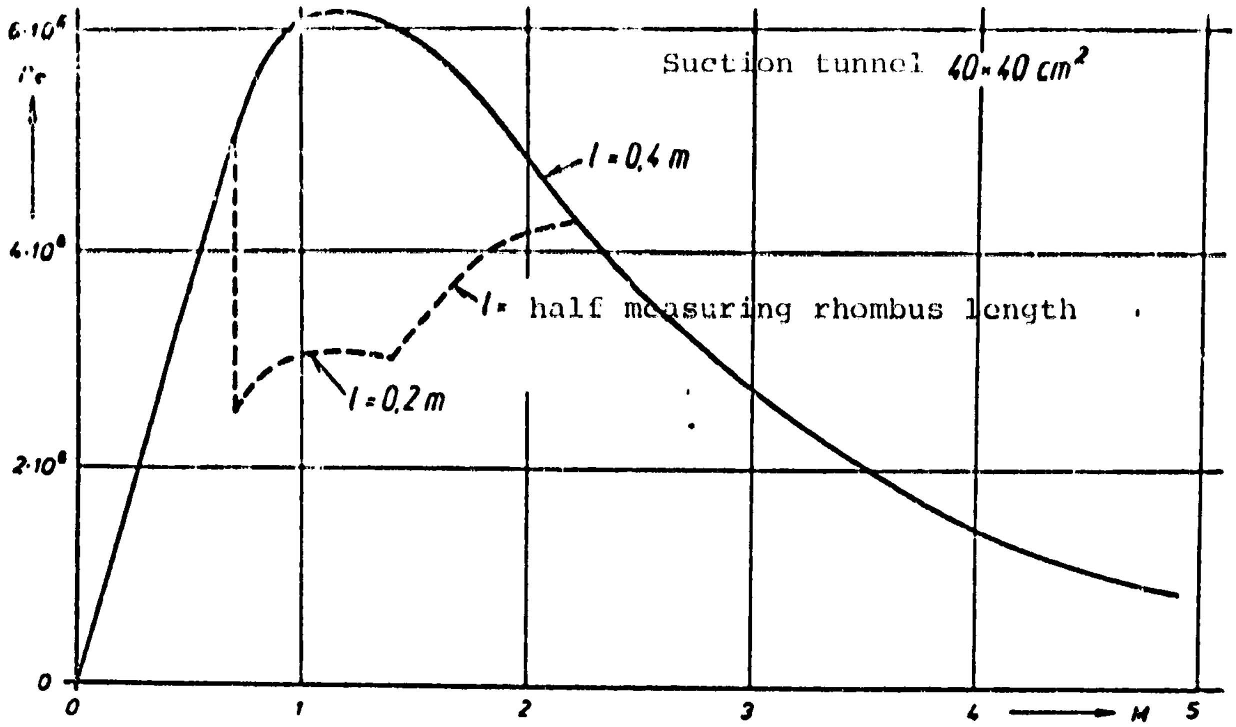

Fig. 5. Maximal Reynolds numbers attainable.

which are attached to the back end of the nozzle blocks. The panels are held in position by six support levers each. Fixed nozzle platforms are attached at the ends of the panels. The support levers are adjusted in such a way that the flexible sheet adjusts with its elastic line so that the nozzle contour for the desired Mach number results in the working section. The support lever paths are controlled on top and bottom with six rocker arms which are attached to a rod which can be moved by a hydraulic cylinder. So that the lever system lies rigidly against the rocker arms, it is pressed by the pneumatic cylinder against the rocker arms.

5.2 Free jet chamber and model support

Downstream of the Laval nozzle (c) or the transonic chamber (d) the free jet chamber (e) is flanged with a high-speed closure. The model support which is suspended in the free jet chamber (Hausammann and Isler company, Zurich) consists of a model holder with a sliding angle device which can be adjusted in transversal direction to the flow direction by 190 mm, and in the direction of flow by 165 mm; and of a pneumatic angle-of-incidence adjustment device. The angle-of-incidence adjusting device operates with differential cylinders connected in series which can be filled on both sides with compressed air. The length of the cylinders is dimensioned to shift the model holder which moves on a circular path by established angle gradings. The following graduations are possible: One /237 cylinder each for 1/2 .1 .2 and 4 and four cylinders for 8 adjustment angles. This results in a total adjustment angle of 39.5. The cylinders may be filled either on one or on the other piston side with compressed air in such a way that any angle can be adjusted in graduations of half a degree between 0 and 39.5. The drive of the cylinders with compressed air is carried out through solenoid valves, which are mounted on the model holder and can be controlled electrically from the exterior. A control unit performs the code conversion of the angles-of-incidence to be set to the required control operations of the solenoid valves.

The maximal adjustment speed of the model support amounts to 20/sec; this high speed has been selected due to the relatively short air-flow times. It can be reduced by an adjustable attenuation. The angle-of-incidence range can be run through by steps or continuously with adjustable speed.

Furthermore, the control unit should be coupled with a process control computer (with the model DEC PDP 8 available in the Aerodynamic Institute) so that a test data processing can be performed during or after the test.

5.3 Diffusor

A bilamellar diffusor (f) with an extremely narrow adjustable cross section is used for the Mach number setting in the supersonic operation. The adjustment is carried out through a hydraulic cylinder with servo drive so that the diffusor cross section can be adjusted to the operation position after the start of the tunnel. The bilamellar diffusor, which compared with the fixed diffusor is more expensive, has been selected as it allows for longer air-flow times. The air-flow times to be expected for both diffusor types are compared in figure 6; zero is already reached at M = 4.1 for the fixed diffusor. For comparative purposes the computer air-flow times for a model with $C_w \cdot F_{Mod}/F_k = 0.04$ are also plotted.

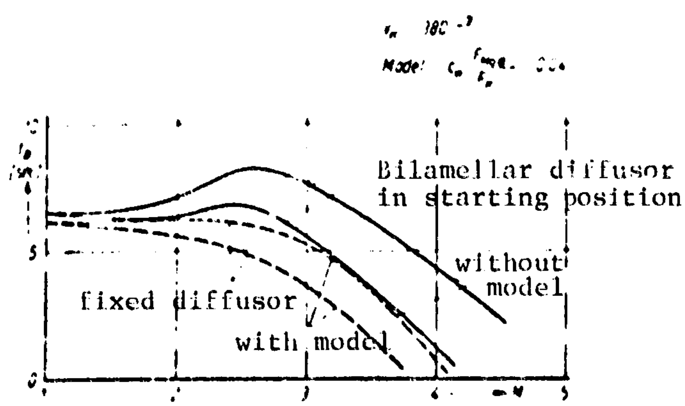

Fig. 6. Air-flow times with different diffusors (without and with model) for a 40 x 40 cm^2 wind tunnel in suction operation with estimated losses.

As the test jet in the free jet chamber is routed laterally only, the diffusor has been designed in such a way that the capture cross section of the diffusor may be changed by a venturi at the exterior. Another gap is located at the back end of the diffusor which establishes a connection to the environmental chamber. The environmental chamber above or below the diffusor panels is connected to the free jet chamber. Because the gap width can be modified from the outside with a venturi, the pressure setting can be adjusted in the free jet chamber.

A fixed diffusor (g) is annexed to the bilamellar diffusor which is used for further pressure recovery in supersonic operation. There the jet adopts the shape of a cylindrical cross-section. Then follows the telescopic tube (h) with the inflatable labyrinth box. When the tunnel is opened the fixed diffusor is moved into the telescopic tube which is flanged to the quick-action stop valve (i).

5.4 Quick-action stop valve

The quick-action stop valve (i) with a nominal width of 800 mm (Hausammann and Isler company), which separates the vacuum tank installation of the wind tunnel, is designed as a single-plate valve; it offers substantial advantages as compared to wedge-type flat slide valves. Its face-to-face dimension of 800 mm is only half of that of the wedge-type valve; it has only one sealing area directed toward the tank and no dome which represents a dead volume which must be sucked into the tank at the start. The valve plate is lighter and can thus be opened faster than the wedge-type valve. In order to match the tank installation, the valve has been designed for a pressure of 13 bar. Furthermore, the valve had to be designed in such a way as to allow for the whole diameter of 800 mm to be unblocked within one second. The valve plate rests on roller bearings on both sides; this allows for sliding with as little friction as possible. On the tank side a circular plate is imbedded in the rectangular valve plate which seals it off toward the tank. The diameter is somewhat larger than the tube diameter (800 mm). On the periphery the plate is sealed with an O-ring against the valve plate; this way a clearance develops between both panels which is accessible through a conduct from the outside. If the tanks are evacuated, the gap is filled with atmospheric pressure through the conduct. This way the panel is pressed onto the sealing surface of the tank. If the valve is to be opened, the tank pressure is fed into the gap; this causes the circular plate to be sucked into the valve plate and to lift from the O-ring seal. This way it is not necessary to overcome friction at the sealing surface when opening the valve. After closing the valve, the gap is again filled with atmospheric pressure. If the tanks are used as pressure reservoirs, the gap is also connected to the tanks and thus the circular plate is pressed onto the seal of the tank.

5.5 Transonic chamber /238

The transonic chamber (d) which can be installed between the Laval nozzle and free jet chamber consistsof the test jet conduit and four separate environmental chambers which are arranged around the test jet conduit. The four environmental chambers can be sucked off separately. The jet is directed by performated metal panels which are arranged at the upper and lower side; the currently fixed sidewalls are replaced at a later date with perforated sheet metal panels. The perforated walls with a thickness of 12 mm consist of two sheet metal panels; the inner sheet is 8 mm thick and the outer sheet 4 mm. The holes are slanted by a 30^{o} angle against the direction of air-flow and have a diameter of 8 mm. They are distributed over the surface in such a way that a maximal average open area of about 10% results. The outer panel can be moved in longitudinal direction. This way, the open area can be modified. In longitudinal direction the perforated panels can be adjusted by $\pm$ 1.5.

6. Manufacture of the Wind Tunnel

The wind tunnel was manufactured by Turbo-Lufttechnik Gmbh, Zweibrücken. Laval nozzle, model support and quick-action stop valve were designed and manufactured by the Hausamman and Isler Company, Zurich. The wind tunnel was installed in the Aerodynamic Institute at the end of 1974 after a construction time of two years. The first test runs were performed on December 20, 1974.

REFERENCES

1. Polhannus, E. C., Kilgore, R. A., Adcock, J. B. and Ray, E. J., "The Langley Cryogenic High Reynolds Number Wind Tunnel Program", Astronautics and Aeronautics, 12, No. 10, 1974.

2. Naumann, A., "Aerodynamische Gesichtspunkte der Windkanalentwicklung" (Aerodynamic Viewpoints of the Wind Tunnel Development), Jahrbuch der Wissenschaftlichen Gesellschaft für Luftfahrt (WGL), 1954.

3. Eggink, H., "Strömungsaufbau und Druckrückgewinnung in Überschallkanälen" (Flow Structure and Pressure Recovery in Supersonic Tunnels), Research Report of the Zentrale f. Wiss. Ber. Wes., No. 1756, Dissertation at Aachen, 1943.

4. Naumann, A., "Wirkungsgrad von Diffusoren bei hohen Unterschallgeschwindigkeiten" (Efficiency Factor of Diffusors at High Subsonic Speeds), Research Report of the Zentrale f. Wiss. Ber. Wes., No. 1738, Dissertation at Aachen, 1942.

5. Hermann, R., "Der Kondensationsstoß in Überschall-Windkanaldüsen" (The Condensation Surge in Supersonic Wind Tunnel Nozzles), Luftfahrtforschung, 19, 1942.

6. Simons, F. P., "Untersuchungen an Diffusoren fur Überschall-Windkanäle" (Investigations of Diffusors for Supersonic Wind Tunnels), Research report of the Zentrale f. Wiss. Ber. Wess., No. 1738, Dissertation at Aachen, 1943.

7. Lukasiewicz, J., "Diffusors for Supersonic Wind Tunnels", Journ. Aeron. Sci., 20, 1953.

8. Pope, A., "Wind Tunnel Testing", John Wiley a. S., New York; Chapman and Hill, London, 1954.

9. Goethert, B., "Windkanalkorrekturen bei hohen Unterschallgeschwindigkeiten" (Wind Tunnel Corrections at High Subsonic Speeds), Jahrbuch der Deutschen Luftfahrtsforschung, 1941.

10. Allen, H. J., "Transonic Wind Tunnel Development of the National Advisory Committee for Aeronautics", Jahrbuch der Wissenschaftlichen Gesellschaft fur Luftfahrt (WGL), 1954.

11. Goethert, B., "Transonic Wind Tunnel Testing", Pergammon Press, 1961.

12. "Wind Tunnel and Model Testing Panel", Papers presented at the Fifth Meeting, AG, 15/P6, 1954.

13. Ferri, A., and Bodgonoff, S. M., "Design and Operation of Intermittent Supersonic Wind Tunnels", AGARDograph 1, 1954.

14. Smolderen, J. J., "Condensation Effects and Air Drying Systems for Supersonic Wind Tunnels", AGARDograph 17, 1956.

15. Berndt, S. B., "Theory of Wall Interference in Transonic Wind-Tunnels", Symposium Transonicum, Aachen 1962, Springer-Verlag, 1964.